

Changes in benthic communities due to submarine volcanic eruption: black coral (*Antipathella wollastoni*) death in the Marine Reserve of El Hierro (Canary Islands)

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RESUMEN

En octubre de 2011 un volcán submarino emergió en los límites de la Reserva Marina del Mar de Las Calmas, en el sur de la isla de El Hierro (islas Canarias, España). Durante seis meses de duración de la erupción, se produjeron importantes alteraciones en la columna de agua de la zona, afectando a comunidades pelágicas y bentónicas. Algunas de estas alteraciones se normalizaron una vez la erupción cesó, pero otras permanecieron. Este estudio presenta el impacto producido por la erupción submarina sobre el coral negro *Antipathella wollastoni* en la zona del infralitoral profundo y el circalitoral superior. Los resultados de las campañas de bionomía realizadas hasta los 60 m de profundidad antes y después de la erupción muestran una mortalidad masiva del coral negro y un descenso en un 81% de su área de distribución. Estos datos representan el impacto más reciente y conocido del volcán sobre la biota del área circundante.

Palabras claves: *Antipathella wollastoni*, volcán submarino, cartografía, comunidad bentónica, degradación del coral, El Hierro, Islas Canarias.

ABSTRACT

In October 2011, a submarine eruption in the south of El Hierro (Canary Islands, Spain) led to the emergence of a submarine volcano on the shallow seabed on the outer boundary of the Marine Reserve of Mar de Las Calmas (MRMC). During the six months of the eruption, significant alterations occurred in the water column, affecting pelagic and benthic communities. Some of these alterations returned to baseline levels when the eruption ceased, but others remain affected. This study presents the impact produced by the eruption on the black coral *Antipathella wollastoni* of the deep infralittoral and upper cir-

calittoral zone. The results of mapping campaigns to a depth of 60 m before and after the eruption show massive mortality of the black coral colonies and a decrease of 81% in its distribution area. These data represent the latest known impact of the volcano on the biota of the surrounding area.

Keywords: *Antipathella wollastoni*, submarine volcano, mapping, benthic community, coral degradation, El Hierro, Canary Islands.

1. INTRODUCTION

Antipathella wollastoni (Gray 1857) is one of only five known species of thorny or black corals of the genus *Antipathella*, order Antipatharia. It is a common species in the Macaronesian archipelagos (Brito & Ocaña 2004) and is also found in the Ceuta littoral and Mediterranean Sea (Ocaña *et al.*, 2007b). This species, like other antipatharians, is a colonial cnidarian with arborescent appearance and characterized by a spiny, branched skeletal axis. It presents a wide bathymetric range between 15 and 520 m (Brito & Ocaña 2004), but in the Canary Islands it is more abundant between 40 and 160 m depth. At these depths, the colonies grow on reefs and rocky slopes where they can form dense aggregations or black coral beds and are one of the most representative communities of the deep rocky infralittoral in the Canary Islands (Martín-García, 2013). Like other corals, antipatharians represent important habitats for a diverse range of associated organisms including decapods, barnacles, bryozoans, echinoderms, caprellids, sponges, hydroids and polychaets, among others (Molodtsova & Budaeva 2007). Colonies of the zoantharia *Antipathozoanthus macaronesicus* (accepted name of *Gerardia macaronesica*) (Ocaña *et al.*, 2007a), the recently described gastropod *Coralliophila kaofitorum* (Vega *et al.*, 2002), and the pedunculate barnacle *Oxynaspis celata* (Brito & Ocaña 2004) are some of the particular species associated with black corals in Canarian waters. However, because this species is found below the depth limits of conventional scuba diving, very little is known about the basic biology and ecology of black corals beds.

In other regions, black corals are harvested for therapeutic uses and to produce jewelry and art (Tsounis *et al.*, 2010). This along with corals inadvertently caught in bottom trawls (Murillo *et al.*, 2010) has led to overexploitation of black coral populations in several regions (Wagner 2011). However, these activities, such as being caught during trawling, do not occur in the Canarian Region. The only human impacts on black coral in the Canarian archipelago are those related to the occupation of habitat or habitat loss by construction activities in the coastal environment and the occasional coral caught by handlines and longlines of the artisanal fishery. These impacts are reduced or null inside the marine reserves, and the intensive scuba-diving at authorized dive sites is the only possible impact on black coral colonies.

In 2011, a new volcano emerged inside the Marine Reserve of Punta Restinga-Mar de Las Calmas (MRMC) on its outer eastern limit (Fig. 1). The shallow submarine eruption started on October 10th, 2011 with more than 12,000 earthquakes and the onset of volcanic tremors (López *et al.*, 2012). The main evidence of the eruption was the discoloration of the surface water observed in the area, detectable from space, related to the discharge of high temperature hydrothermal fluids as well as magmatic gases, CO₂, H₂S and metals

(Santana-Casiano *et al.*, 2013). Abundant rock fragments were found floating on the ocean surface during the first months of the eruption (Santana-Casiano *et al.*, 2013). The volcano was located on a rift with the lava flowing south-westwards at a depth of 350 m below sea level, 1.8 km south of El Hierro. In January 2012, the cone had risen to a depth of 130 m, and in February it reached its maximum elevation of 88 m below sea level. On March 5th 2012, local authorities announced the end of the eruption.

The decrease in oxygen, the acidification, fertilization and deposition of chemicals during the eruption affected the entire area southwest and northeast of the island; however, this affected area was reduced to 0.5 km around the volcano in the post-eruptive phase (Santana-Casiano *et al.*, 2013). These processes did not just cause significant changes in the water column (Fraile-Nuez *et al.*, 2012) but had drastic consequences on the planktonic, pelagic and benthic communities of the southwest of the island, even inside the marine reserve (Sangil, 2013; Ariza *et al.*, 2014). The University of La Laguna headed the studies into the effect of the submarine volcano on benthic communities and detected that a few days before the submarine eruption some algae assemblages, such as those dominated by *Lobophora variegata* and coralline species had been drastically reduced and replaced by ephemeral algae (Sangil, 2013). These initial studies were carried out by scuba diving in 12 locations up to 20 m depth; spread along the southwestern side of the island, inside and outside the reserve (Sangil, 2013). However, the methodology employed in these campaigns did not provide information on the extension of the changes in the communities nor the possible impacts of the eruption on deep species or communities.

The Spanish Institute of Oceanography (IEO) was the institution in charge of the main cartographic studies, sampling and video recordings of the volcano with a ROV and photogrammetric sled on board the Oceanographic Ship Ramón Margalef. All of the samples and recordings were taken a few weeks after the eruption finished. The images showed the seabed and the remaining marine life in nine locations between 150 and 480 m depth and 6-1 km from the volcanic cone (González-Porto *et al.*, 2012). Therefore, the seabed around the volcano between 20 and 150 m has remained unstudied until now.

This paper describes the changes observed in the black coral communities of the infralittoral zone in the MRMC before and after the submarine eruption in the south of El Hierro. The results are based on video sampling to enable us to map and provide information on the infralittoral communities up to 60 m.

2. MATERIAL AND METHODS

Since the local authorities announced the end of the eruption and allowed scientific monitoring in the affected area, between March 2012 and October 2014, visual inspections have been conducted in various locations with scuba-diving and video observations with a ROV VIDEORAY EXPLORER between 0-60 m. In the latest surveys, we took photographs of the black coral colonies with a Nikon D300S Camera.

For the mapping, two sampling surveys were undertaken in the reserve, one in July 2010 and recently a second survey in October 2014. The study focused on the infralittoral zone to a depth of 60 m, although we took some deeper samples when the weather conditions permitted it. The sampling process for data collection was consistent with the method

described by Barquín-Diez *et al.*, 2003 using video samples with an underwater TV system. In total, 232 samples were taken inside the MRMC in 2010, 110 samples deeper than 30 m. In 2014, a further 110 samples and 20 video samples were repeated in the same localities that had the presence of black coral in 2010. Later, we used the information about the presence and absence of the communities and the software Maxent v3.3.3 (Phillips & Dudík, 2008) to create distribution models and distribution maps according to Martín-García *et al.*, 2013.

3. RESULTS

Initial observations by scuba-diving and ROV in three locations with black coral habitats provided clear evidence of the significant impact of the eruption on the colonies of most of locations visited. They showed the massive mortality of most of the black coral colonies and an intensive epibiosis on the dead branches (Fig 1, 2).

In 2010, a total of 28 video-samples showed dense communities of black coral in the MRMC. All of them were located along rocky slopes between 41 and 90 m depth in most of the marine reserve. The distribution maps obtained from the samples in July 2010 from depths of up to 60 m indicated that *A. wollastoni* formed dense corals in a continuous band between 30-60 m depth inside the marine reserve and occupied 9 Ha of the infralittoral zone (Fig. 1) and 11.3% of the seabed between these depths. The results of this study also demonstrated that the community dominated by the brown algae *L. variegata* and red filamentous algae was the most representative in infralittoral zone (Table 1).

By contrast, in October 2014, eleven of the 20 locations that showed dense forests of black coral before the eruption only had dead colonies present that had been overgrown by epibionts. Only four locations registered colonies with live polyps of black corals. In general these few specimens indicate a possible recovery before the end of the eruption. The resulting mapping from the data collected in 2014 shows a black coral distribution area of 3 Ha (Table 1). This represents a decline of 81% compared to the previous distribution area

Table 1. The total extension in hectares (Ha) occupied by the main benthic communities mapped in 2010 and 2014, and the difference between these cartographies (in hectares and percentage) in the MRMC.

Benthic communities	Area (Ha)			
	2010	2014	2010-14	%
<i>Lobophora variegata</i> and red filamentous seaweeds	151	159	8.4	5.6
Maërl	42	42	-0.1	-0.2
<i>Lophocladia trichoclados</i> and <i>Cotoniella filamentosa</i>	25	26	1.0	3.9
Brown garden eel (<i>Heteroconger longissimus</i>)	24	25	1.7	7.4
Sandy bottoms without macroscopic communities	20	15	-4.5	-23.2
<i>Antipathella wollastoni</i>	8	2	-6.5	-80.9

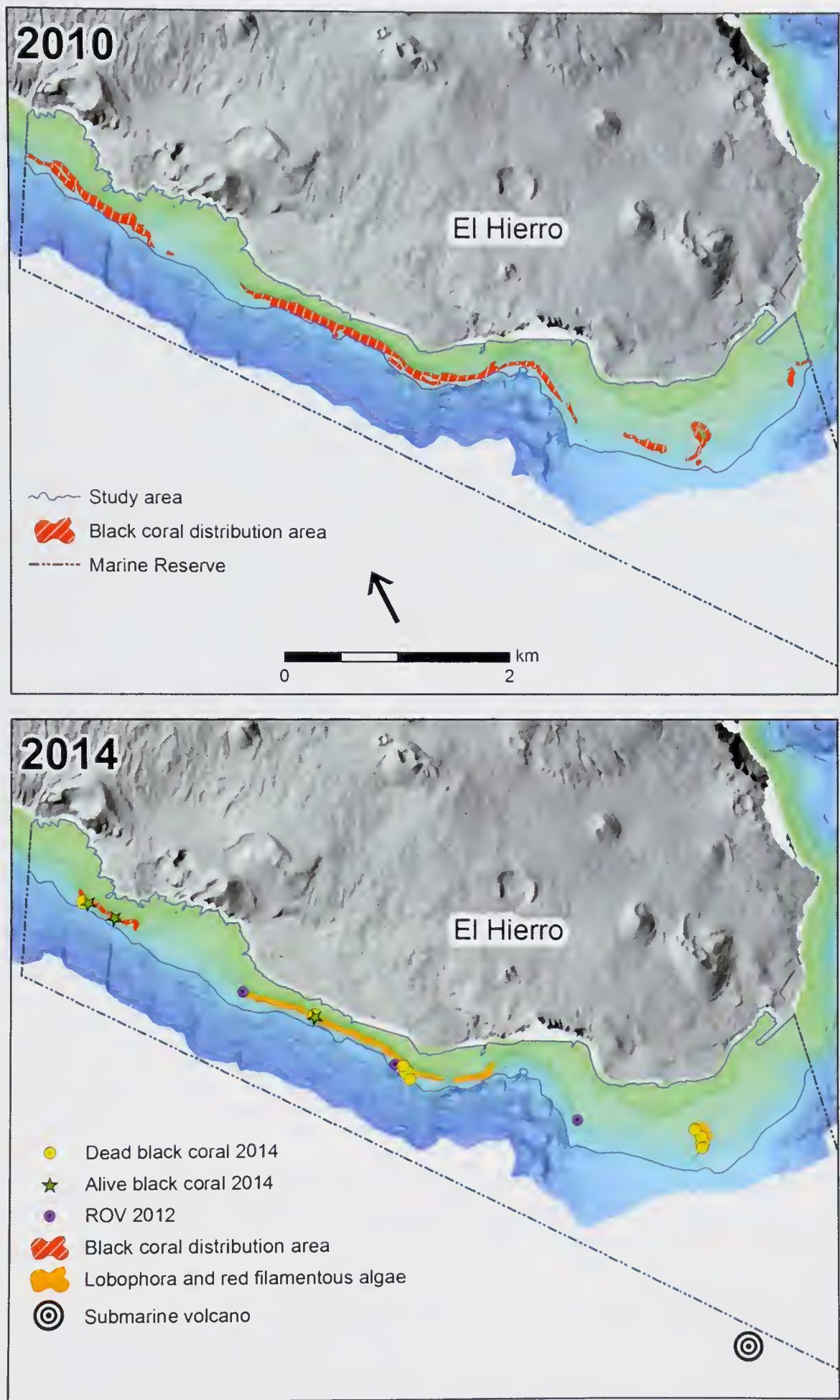


Figure 1. Distribution maps of black coral communities in the MRMC in 2010 and 2014 and locations with dead and live corals according to observations and sampling before the volcano eruption.

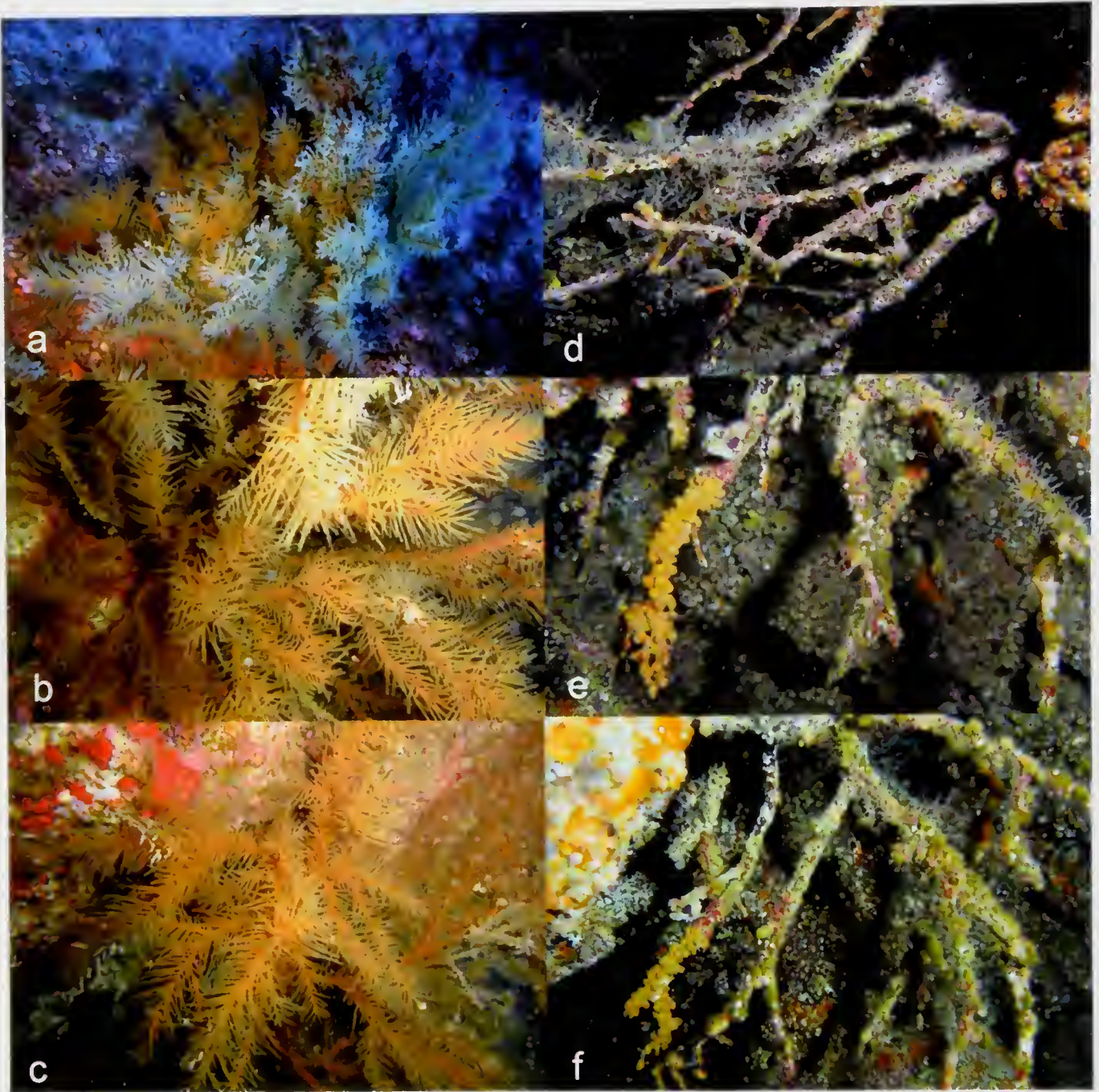


Figure 2. Photographs of black coral at some locations of the MRMC before (a-c) and after (d-f) the submarine eruption.

(Fig. 1). The area lost by corals is now covered by the brown algae *L. variegata* and red filamentous seaweeds, which respond in part to the observed increase in the extension of this community of algae (Table 1). This result is contrary to that obtained by Sangil *et al.* (2013), who document an initial regression in the abundance of *L. variegata*, whereas our result indicates a quick recovery of the algae community.

Other benthic communities have not suffered such severe changes in their distribution areas, or they have recovered faster. Soft bottoms, especially when they are not covered by benthic algae that can attach to them, have considerable seasonal mobility, which is even higher when they are in shallow waters, so the differences observed in the results are within the normal range.

4. DISCUSSION

There are various causes of black coral mortality but only a few are the result of natural disturbances. The volcano chiefly affected the layer between 75 and 125 m in depth, which experienced oxygen depletion to almost anoxic levels, enhanced light attenuation, pH decrease, higher concentrations of dissolved metals, among others (Santana-Casiano *et al.*, 2013). It is possible that all of these conditions would cause mortality of black coral, but there are no studies that have analyzed the effect of these characteristics on the survival of this species. However, according to the literature, it is more likely that the intense sedimentation of the submarine eruption has been the main factor that caused the massive mortality of black coral in the area, and later a subsequent process of intense epiphytism on the branches of dead coral occurred. The numerous pinnules of the branches of *A. wollastoni* facilitate retention of sediment, coating and silting polyps preventing feeding and respiration. Sedimentation is an important factor that can kill corals (Perez *et al.*, 2014). Suspended sediment also reduces irradiance and negatively affects coral growth (Anthony & Connolly, 2004). Olsen & Wood (1980) attributed substantial damage to shallow-water populations of *Aphanipathes salix* and *Plumapathes pennacea* in the Caribbean Sea to a hurricane. Furthermore, in shallow-water, black coral populations (*Antipathes fiordensis*) in the fiords of New Zealand are frequently affected by terrestrial landslides. These landslides produce sediment clouds that settle over benthic organisms such as black corals (Jiang *et al.*, 2015). Sedimentation events may limit both black coral abundances as well as their upper depth limit (Jiang *et al.*, 2015).

Elsewhere in the world, there have been cases of massive mortalities of corals but for very different reasons like the overgrowth of black corals by epibiotic organisms such as sponges and other corals (Kahng & Grigg, 2005, Wagner 2011). Some of these cases of invasion are partially attributable to anthropogenic disturbance (Kahng & Grigg, 2005). In the Canary Islands, black corals have a great number of epibiotic species, especially hexacorallia *Antipathozoanthus macaronesicus* (Fig. 2D-F), but epibiota has never been recorded as a cause of massive mortality of black coral colonies. Generally, it is a process that occurs after the death of hard corals.

In conclusion, it is essential to monitor benthic communities from the very beginning of an anomaly and continue over time to estimate the long-term changes. In the case of black corals, there are still many knowledge gaps about their biology or ecology that need to be covered and Marine Reserves represent the ideal setting for the development of this type of work.

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6. REFERENCES

- ANTHONY, K.R.N., S.R. CONNOLLY 2004. Environmental limits to growth: physiological niche boundaries of corals along turbidity-light gradients. *Oecologia* 141: 373-384.
- ARIZA, A., S.KAARTVEDT, A. RØSTAD, J.C. GARIJO, J. ARÍSTEGUI, E. FRAILE-NUEZ, S. HERNÁNDEZ-LEÓN. 2014. The Submarine Volcano Eruption off El Hierro Island: Effects on the Scattering Migrant Biota and the Evolution of the Pelagic Communities. *PLoS ONE* 9 (7): e102354.
- BARQUÍN-DIEZ, J., G.GONZÁLEZ, M.C. GIL. 2003. Un método de estudio de bionomía bentónica utilizado en las costas canarias para fondos poco profundos. *Vieraea* 31: 219-231.
- BRITO, A, O. OCAÑA. 2004. *Corales de las Islas Canarias*. Francisco Lemus (Ed.). Tenerife. 477 pp.
- FRAILE-NUEZ, E., M.GONZÁLEZ, J.M. SANTANA, J. ARÍSTEGUI, I.J. ALONSO, S. HERNÁNDEZ, M.J. BLANCO, A. RODRÍGUEZ, A. HERNÁNDEZ, M.D. GELADO, *et al.* 2012. The submarine volcano eruption at the island of El Hierro: physical-chemical perturbation and biological response. *Scientific Reports* 2: 486 [doi: 10.1038/srep00486].
- GONZÁLEZ-PORTO, M, B. ALMÓN, A. GARCÍA-ALEGRE, A. BRITO, F. SÁNCHEZ, P. MARTÍN-SOSA. 2012. Submarine habitat images around El Hierro volcano. In: Borja A (ed), 2012. XVII Iberian Symposium on Marine Biology Studies. *Revista de Investigación Marina, AZTI-Tecnalia*, p 298.
- GRAY, J.E. 1857. Synopsis of the families and genera of *Axiferous zoophytes* or barked corals. *Proceedings of the Zoological Society of London*, 25: 278-294.
- JIANG, W., C. CORNELISEN, B. KNIGHT, M. GIBBS. 2015. A pattern-oriented model for assessing effects of weather and freshwater discharge on black coral (*Antipathes fiordensis*) distribution in a fjord. *Ecological Modelling* 304: 59-68.
- KAHNG, S.E., R.W. GRIGG. 2005. Impact of an alien octocoral, *Carijoa riisei*, on black corals in Hawaii. *Coral Reefs* 24: 556-562.
- LÓPEZ, C., M.J. BLANCO, R. ABELLA, B. BRENES, V.M. CABRERA, B. CASAS, I. DOMÍNGUEZ, A. FELPETO, M. FERNÁNDEZ DE VILLALTA, C. DEL FRESNO, *et al.* 2012. Monitoring the volcanic unrest of El Hierro (Canary Islands) before the onset of the 2011-2012 submarine eruption. *Geophysical Research Letters* 39: L13303.
- MARTÍN-GARCÍA, L, G. GONZÁLEZ-LORENZO, I.T. BRITO-IZQUIERDO, J. BARQUÍN-DIEZ. 2013. Use of topographic predictors for macrobenthic community mapping in the Marine Reserve of La Palma (Canary Islands, Spain). *Ecological Modelling* 263: 19-31.
- MARTÍN-GARCÍA, L. 2013. *La distribución especial de las comunidades bentónicas infralitorales de Canarias y su importancia en la gestión del medio marino*. Ph.D. thesis, University of La Laguna, p 245.
- MOLODTSOVA, T.N., N. BUDAEVA. 2007. Modifications of corallum morphology in black corals as an effect of associated fauna. *Bulletin of Marine Science* 81(3): 469-479.

- MURILLO, F.J., P. DURAN MUÑOZ, A. ALTUNA, A. SERRANO. 2010. Distribution of deep-water corals of the Flemish Cap, Flemish Pass, and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): interaction with fishing activities. *ICES Journal of Marine Science* 68(2):319-332.
- OCAÑA, O., A. BRITO, G. GONZÁLEZ, R. HERRERA. 2007a. Additions in relation to Gerardiidae from the Macaronesian waters and the Mediterranean Sea (Anthozoa: Zoantharia). *Vieraea* 35:163-168.
- OCAÑA, O., D.M. OPRESKO, A. BRITO. 2007b. First record of the black coral *Antipathella wollastoni* (Anthozoa: Antipatharia) outside of macaronesian waters. *Revista de la Academia Canaria de Ciencias* 18 (4): 125-138.
- OLSEN, D.A., R.S. WOOD. 1980. *Investigations on black coral in Salt River Submarine Canyon St. Croix, U.S. Virgin Islands*. Final Scientific Report 80-12. Division of Fish and Wildlife U.S. Virgin Islands NULS-I Mission 79-5 and 80-12, p 25.
- PEREZ, K. III, K.S. RODGERS, P.L. JOKIEL, C.V. LAGER, D.J. LAGER. 2014. Effects of terrigenous sediment on settlement and survival of the reef coral *Pocillopora damicornis*. *PeerJ* 2: e387 [doi: 10.7717/peerj.387].
- PHILLIPS, S.J., M. DUDÍK. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* 31: 161-175.
- SANGIL, C. 2013. Cambios en la biodiversidad vegetal submarina del Mar de Las Calmas tras la erupción volcánica de La Restinga: una oportunidad para profundizar en el conocimiento de los ecosistemas marinos de Canarias. In: Afonso-Carrillo J (ed) *El Hierro - Nacimiento de un volcán*. Instituto de Estudios Hispánicos de Canarias, Puerto de la Cruz, pp 55-82.
- SANTANA-CASIANO, J.M., M. GONZÁLEZ-DÁVILA, E. FRAILE-NUEZ, D. DE ARMAS, A.G. GONZÁLEZ, J.F. DOMÍNGUEZ-YANES, J. ESCÁNEZ. 2013. The natural ocean acidification and fertilization event caused by the submarine eruption of El Hierro. *Scientific Reports* 3: 1140 [doi: 10.1038/srep01140].
- TSOUNIS, G., S. ROSSI, R.W. GRIGG, G. SANTANGELO, L. BRAMANTI, J.M. GILI. 2010. The exploitation and conservation of precious corals. *Oceanography and Marine Biology - An Annual Review* 48:161-212.
- VEGA, R., R. VEGA, Á.A. LUQUE 2002. *Coralliophila kaofitorum*, a new species (Gastropoda: Coralliophilidae) from the Canary Islands living on *Antipathes wollastoni* (Cnidaria: Anthozoa: Antipatharia). *The Nautilus* 116(2): 50-55.
- WAGNER, D. 2011. *The biology and ecology of hawaiian black corals (Cnidaria: Anthozoa: Hexacorallia: Antipatharia)*. Ph.D. thesis. The University of Hawai, pp 167.